DESIGNING STEM-INTEGRATED LESSONS WITH A FOCUS ON PHUKET'S CONTEXT IN ELEMENTARY CLASSROOMS THROUGH MODEL-ELICITING ACTIVITIES: A COLLABORATIVE PROFESSIONAL DEVELOPMENT PROGRAM FOR SCIENCE COACHES AND TEACHERS

S. Chatmaneerungcharoen

Phuket Rajabhat University (THAILAND)

Abstract

This study highlights a collaborative initiative between schools and universities to develop a professional development framework aimed at integrating STEM (Science, Technology, Engineering, and Mathematics) into K-6 science classrooms. Utilizing design-based implementation research, university facilitators collaborated with six science student teachers and coaches to create an accessible vision of STEM integration, grounded in the principles of Model-Eliciting Activities (MEAs). MEAs are open-ended, real-world problem-solving tasks designed to help students develop scientific models and deepen their understanding of key concepts. The researchers designed a flexible professional development approach with three primary goals: (1) assessing participants' diverse experiences in integrating STEM into the curriculum, (2) promoting a new perspective on STEM integration through open-ended science problems rooted in real-world contexts, and (3) emphasizing the explicit inclusion of science content. Qualitative analysis, including participant discussions, written reflections, and classroom observations, revealed participants' readiness to implement MEAs as a method for integrating STEM into K-6 classes. However, participants also recognized the need for ongoing support to address challenges such as curriculum pacing and administrative expectations. The results of this research suggest that this collaborative effort can significantly enhance STEM integration, particularly within the unique natural resource context of Phuket. This approach not only fosters STEM instructional leadership but also encourages transdisciplinary integration and prepares students for STEM-related roles and careers.

Keywords: Model-eliciting activity, Professional development, STEM integration, Science coaching, Design-based implementation research.

1 INTRODUCTION

Phuket, Thailand's largest island, stands as one of Southeast Asia's top tourist destinations, celebrated for its stunning beaches, vibrant nightlife, and rich cultural heritage. With a history that spans thousands of years, Phuket has played a vital role in ancient maritime trade routes linking India, China, and Southeast Asia. From the 16th century onwards, the island became renowned for its tin mines, attracting Portuguese, Dutch, British, and French traders. The island's cultural fabric, influenced by centuries of trade and migration, is a diverse blend of Thai, Chinese, Malay, and Indian influences. This rich cultural and historical background offers valuable learning resources that can engage local students and enrich their educational experiences. However, a key challenge for educators is helping Thai teachers connect classroom learning with real-world experiences, bridging the gap between academic lessons and the broader global context. In a rapidly evolving world shaped by technological innovation and globalization, education must adapt to prepare students for life in an interconnected society. By integrating local history with global awareness, educators can equip students with the skills necessary to become 21st-century citizens, capable of thriving in a digital and globalized world. Education, now more than ever, plays a central role in this transformative era. It must move beyond traditional subjects and embrace innovative strategies that foster a deep understanding of global interconnectedness, social justice, and sustainable development. By emphasizing cultural literacy, equality, and respect, educators aim to nurture individuals who are not only proficient in academic knowledge but also possess the critical thinking and global awareness needed to navigate a world of diverse challenges and opportunities (Abdurrahman, 2019). In this dynamic educational landscape, integrating technology into teaching practices has become essential. Technological Pedagogical Content Knowledge (TPACK) represents the intersection of three critical domains: technology, pedagogy, and content knowledge. This integration is particularly crucial in STEM (Science, Technology, Engineering, and Mathematics) education, where mastery of technology is indispensable. STEM professionals today must be proficient in the technologies specific

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to their fields, whether it is scientists mastering scientific tools or engineers utilizing computer-assisted design (CAD) software. Although STEM Education is promoted as an instructional approach to be implemented in Thai curriculum (Ministry of Education Thailand, 2017), there was no STEM subjects in this school-based curriculum. Instead, science teachers were able to independently design the STEM activities based on their own instructional design without school-level administrative regulations. Teachers need to leverage TPACK to design effective STEM lessons that integrate both technology and content knowledge. A key element in engineering education is engineering design—a vital competency that students must acquire. Teacher education plays a crucial role in helping future science educators provide learners with authentic, “real-world” engineering design experiences. Research shows that learning is complex; expertise is not simply the result of accumulated knowledge or years of experience. By understanding what advanced engineers know and can do, teachers can better support learners in developing expert-like practices and knowledge.

One method for teaching these skills to undergraduate STEM student teachers is through Model-eliciting activities (MEAs). MEAs present complex, real-world problem-solving tasks set in a realistic context with a client, making them an authentic form of assessment. The solutions developed by students are generalizable models that reveal their thought processes, including both procedural methods and metaphors for interpreting information. In MEAs, student teams of three to four collaborate to express their models, test them using sample data, and refine their approaches to meet societal needs. This framework not only teaches engineering content but also addresses broader accreditation criteria, fostering the development of essential skills for 21st-century learners. Professional development (PD) experiences can facilitate learning opportunities for teachers to acquire knowledge about new teaching practices or content (Borko et al. 2008; Guskey 1986; 2002).

Numerous STEM studies have highlighted that effective professional learning programs must be active, sustained, coherent, collaborative, reflective, and focused on content knowledge to result in meaningful changes in teaching practice (Garet et al., 2001). While various professional development (PD) opportunities exist for integrating STEM education at the elementary level, there is limited research exploring the specific knowledge and skills necessary for teaching integrated STEM, particularly how to effectively integrate these elements. Furthermore, there is a need for more research on how these skills can be effectively communicated to promote the widespread implementation of integrated STEM in elementary classrooms ((Guzey et al., 2014; Brophy et al., 2008; Roehrig et al., 2012). Existing research often emphasizes student development in scientific knowledge and engineering design process skills, but few studies provide detailed insights into the teaching process, particularly in relation to engineering design. This study aimed to design professional learning opportunities that incorporate Technological Pedagogical Content Knowledge (TPACK) and Model-Eliciting Activities (MEAs) as applied to STEM teaching. It focused on contextualizing engineering design challenges that teachers could use to effectively integrate STEM concepts into elementary classrooms. Both TPACK and STEM education aim to develop students' 21st-century skills (Mishra & Koehler, 2006; Hoeg & Bencze, 2017). Parker et al. (2015) have linked teachers' TPACK with STEM education, advocating for the integration of these two domains. As a result, this study employs the TPACK framework alongside the MEA method to design professional development programs that address technology, pedagogy, and content within current TPACK-STEM teacher professional learning initiatives. One key question arises: What constitutes practical professional development that can help student teachers fully understand what the engineering design process looks like in a real classroom? To address this, two sub-questions are explored: (1) What specific aspects of the MEAs method contribute to the development of student teachers' TPACK for STEM? and (2) How does the collaboration between student teachers, cooperating teachers, and university mentors impact the effectiveness of MEAs in building TPACK for STEM? Additionally, two related questions are investigated: (2.1) What are the primary ways in which student teachers adapted their use of MEAs? and (2.2) What insights from post-lesson discussions help clarify the reasons behind changes in TPACK for STEM? To explore these questions, the study presents a detailed account of the methodology, findings, discussions, and implications in the following sections.

2 METHODOLOGY

2.1 Research design

The study employed a multiple case study design within the social-constructivist paradigm (Bell & Gilbert, 2005), comparing findings from four distinct clusters to explore both differences and similarities in how MEAs were adapted. The comparison focused on how the MEA approach supported science student teachers in developing their Technological Pedagogical Content Knowledge (TPACK) for STEM through collaboration with cooperating teachers and university mentors. The study examined how these collaborative efforts and adaptations contributed to the growth of student teachers' technological, pedagogical, and content knowledge in STEM education. The research was conducted in the context of the Integrated Science Teaching Management Course, an elective course within the Department of General Science Education at a university in Thailand. This study was part of the Outdoor STEM Project, which received funding from Phuket Rajabhat University and PMU (Area-based Education Fund).

2.2 Setting

This study was conducted in partnership with internship schools affiliated with the university. These schools offer education from first grade to twelfth grade, supporting students in achieving both academic and ethical excellence to enrich their lives. The research was carried out over a period of one year and two months, from 2022 to 2023, as part of a broader initiative aimed at developing teacher education programs.

2.3 Participants

The participants were six student teachers, six cooperating teachers and a university mentor were invited to be the participants of the study. These six student teachers voluntarily formed six case studies (named as AST, BST, etc.). The participants' pseudonym names and their groups were presented in the Table 1. Prior to making their decisions to join this study. They were selected by purposive sampling.

Table 1. The participants' pseudonym names

Student teacher	***Cooperative teacher***	***Grade***	***Subject***
AST	ACT	4-6	Science, STEM
BST	BCT	4-6	STEM
CST	CCT	3-5	Science
DST	DCT	2-3	Science, STEM
EST	ECT	5-6	Science
GST	GCT	4-6	STEM

Note: ST (Student) and CT (Cooperative Teacher)

2.4 TPACK-MEAs Program

Designing a teacher professional development program centered around the Engineering Design Process (EDP) using Model-Eliciting Activities (MEAs) can empower educators to effectively integrate STEM-based learning into their classrooms. The TPACK-MEAs program framework, which integrates Technological Pedagogical Content Knowledge (TPACK) with MEAs, is outlined in Table 2, providing a structured approach to support teachers in using EDP and MEAs to foster critical thinking, problem-solving, and innovation in students.

Table 2. TPACK-MEAs program

Program Objectives

- Equip teachers with knowledge and skills to incorporate the EDP using MEAs in the classroom.
- Enhance students' problem-solving, critical thinking, and innovation skills through hands-on engineering challenges.
- Foster a student-centered learning environment that aligns with real-world engineering practices.

Phase	Step of Teacher Training	Purpose of Step	Activity
Phase 1 2-4 Weeks	Introduction to the Engineering Design Process	Familiarize teachers with the steps of the EDP: Ask, Imagine, Plan, Create, Test, and Improve.	- Interactive workshops covering each step of the process. - Case studies from real-world engineering projects. - Discussion of the benefits of EDP for fostering creativity and problem-solving.
	Interactive workshops covering each step of the process.	Help teachers integrate EDP into various subjects, especially STEM (Science, Technology, Engineering, Mathematics).	- Curriculum mapping to align EDP with existing lesson plans. - Designing interdisciplinary projects using the EDP (e.g., integrating math, science, and technology in an engineering challenge). - Assessment strategies for evaluating student performance in engineering tasks.
Phase 2 1 semester	Hands-on EDP Challenges	Engage teachers in practical, hands-on projects where they experience the EDP firsthand.	- Designing interdisciplinary projects using the EDP with MEAs (e.g., integrating math, science, and technology in an engineering challenge and model designing). MEAs are open-ended problems that require students to develop models to solve real-world issues, encouraging deeper engagement with the EDP. These projects can involve students using the EDP to propose, test, and refine models that address complex problems, ensuring that they apply both mathematical reasoning and scientific principles throughout the engineering challenge. - Group projects (e.g., designing a bridge, building a simple machine, or creating a sustainable product). - Reflection on the challenges faced and the importance of iteration in the design process. - Peer review and sharing best practices for facilitating these challenges in the classroom. - Assessment strategies for evaluating student performance in engineering tasks.
	Classroom Implementation Strategies	Equip teachers with strategies to effectively guide students through the EDP with MEAs	- Differentiated instruction techniques for students at various skill levels. - Classroom management strategies for group work during EDP projects. - Incorporating technology tools (e.g., iPad Apps, CAD software, simulation programs) to enhance the design experience.
Phase 3 1 year Ongoing, with periodic check-ins and meetups	Collaboration and Reflection	Encourage collaboration among teachers and reflection on their teaching practices	- Regular teacher meetups or professional learning communities (PLCs) to share experiences, resources, and challenges. - Reflective journaling on the successes and challenges of using EDP in the classroom. - Incorporation of feedback loops with school administrators for ongoing support.
	Assessment and Continuous Improvement	Develop methods to assess student learning and teacher effectiveness in implementing the EDP with MEAs	- Developing rubrics to assess student projects based on the EDP. - Gathering student feedback to refine lesson plans. - Self-assessment tools for teachers to evaluate their own implementation of the EDP with MEAs.

2.5 Research Instruments and data collection

Data were gathered from participants' MEAs (Model-Eliciting Activities), their solutions, and semi-structured interviews. Researchers analyzed the MEA lesson plans and student teachers' reflective journals, then tailored interview questions for each group. While some questions were asked across all groups to explore general MEA principles, others were customized to address each group's specific MEA and solution. The common questions and their related principles are outlined in table 3:

Table 3. Questions and Data Collection Methods Aligned with Related Principles

MEAs Principle	*Questions to Encourage Student Discussion*	*Data collection*
Model Construction Principle	Does the problem situation require the construction of a mathematical model? Please explain.	Group discussion, Interview with challenging situations, reflective journal
Reality Principle	Do you believe the problem situation is meaningful for students and connected to their lives and experiences? Please elaborate	
Self-Assessment Principle	In your opinion, are students able to assess the validity of alternative solutions? Why or why not?	
Construct Documentation Principle	How effectively do you think students can articulate their ideas? Please provide examples?	
Construct Shareability and Reusability Principle	Can the constructed model be shared and reused? What are your thoughts on this?	
Effective Prototype Principle	To what extent do you think the constructed model is meaningful to others, and can the problem situation serve as a useful prototype for similar scenarios? Please explain.	

3 RESULTS

Research data were collected through an independent analysis of the MEAs and their corresponding solutions as outlined in the participants' lesson plans, focusing on their alignment with established MEA principles. During this content analysis, both the MEA documents and interview transcripts were thoroughly examined to identify participants' references to these principles. The analysis revealed that while some MEAs aligned well with certain principles, others presented challenges. For example, the **Effective Prototype Principle** was not always explicitly demonstrated, as student teachers often needed more time to fully grasp and apply the problem statement and solution to future scenarios. However, despite this, the MEA content, the solutions developed by participants, and interview data suggested that the Effective Prototype Principle could still be inferred. In some instances, participants noted difficulty in aligning with certain principles, largely due to the limited modeling instruction available in the local educational context. The researchers evaluated the appropriateness of each MEA by analyzing its structure and categorizing data according to specific MEA principles. The data collection and analysis processes were meticulously documented, with findings supported by excerpts from MEAs and participant statements from interviews. As part of the TPACK-MEAs Program for STEM, 12 teachers designed and implemented their own lesson plans incorporating MEAs during their engineering instruction, offering further insights into the program's effectiveness. The teachers demonstrated their ability to implement MEAs, as outlined in Table 4, showcasing their skills in designing and applying these activities within their lesson plans.

Table 4. Teachers' ability to Use MEAs

Engineering Design Process	*Model Eliciting Activity*
Define the Problem engineers discover the problem and they identify the project criteria and constraints. This step may include completing a design brief.	Select a Real-World STEM Problem Choose a problem that is authentic, complex, and open-ended, relating to a real-world scenario in science, technology, engineering, or mathematics. The problem are presented in a way that students understand its relevance to STEM fields and their everyday lives. Ensure that the problem statement is open-ended, with room for multiple solutions. - Example Problem: "A local city is facing regular flooding due to climate change. As environmental engineers, you need to create a model to predict the flooding risk based on weather patterns and suggest ways to mitigate it using eco-friendly technology (AST, ACT, BST, BCT, CST, CCT,DST,DCT,EST,ECT,GST, GCT)
Generate Concepts Next, engineers conduct background research to learn more about the problem and possible solutions. Then they brainstorm how they will solve the problem and select the best idea to develop by comparing their brainstormed solutions to the project requirements. This step may include completing a decision matrix.	Teachers guide students in clearly defining the problem and conducting background research to gather relevant information and explore potential solutions. Following this, students brainstorm various approaches to solve the problem, considering different perspectives and ideas. They then evaluate their brainstormed solutions against the project's requirements, selecting the most feasible and effective solution. This step may also include developing preliminary models or prototypes and gathering feedback to refine their ideas before moving on to the detailed design phase. (ACT, BST, BCT, CST, CCT,DCT,EST,ECT,GST, GCT)

Engineering Design Process	*Model Eliciting Activity*
Develop a Solution Then engineers create a detailed sketch of the chosen solution and identify the materials needed to bring it to life.	The problem requires students to apply their STEM knowledge to develop a model that provides a solution. - Science Example: Develop a model for predicting the environmental impact of plastic waste in oceans and propose a method to reduce it. - Technology Example: Create a model to optimize the layout of a new website for an e-commerce company to increase customer engagement. - Engineering Example: Design a model for an energy-efficient bridge that can withstand extreme weather conditions. - Mathematics Example: Construct a model to calculate the most efficient way to distribute resources during a natural disaster. Promote Application of STEM Knowledge The model construction phase should allow students to apply relevant STEM concepts. Provide them with resources, such as data sets, software tools, or lab materials, depending on the focus of the activity. -Technology: Students can use programming or simulation tools to test different scenarios. - Mathematics: Encourage students to use mathematical models, such as differential equations or statistical analysis, to represent real-world phenomena. (AST, ACT, BST, BCT, CST, CCT,DST,DCT,EST,ECT,GST, GCT)
Construct and Test Prototype Next, a testable model of the chosen solution is built. Observations are made and data is collected during the test.	Organize Students into Collaborative Groups where students collaborate, discuss, and brainstorm ideas. Group collaboration encourages them to combine their knowledge in different STEM areas, fostering interdisciplinary thinking. - Assign roles to students based on their strengths, such as data analysts, model designers, or research coordinators, to enhance collaboration. Encourage Model Construction Guide students to build a mathematical, conceptual, or physical model that addresses the problem. Encourage them to think critically about the factors involved, make assumptions, and create a systematic way to approach the problem. - Science Example: Students may use data analysis and environmental science principles to predict flood risks, incorporating variables like rainfall, soil absorption rates, and urban infrastructure. -Engineering Example: Students might design a physical prototype or use simulation software to test their flood prevention model. (AST, ACT, BST, BCT, CST, CCT,DST,DCT,EST,ECT,GST, GCT)
Evaluate Solution Then analyze the data and determine the effectiveness of the solution. Does it solve the problem? Were the criteria and constraints met? This step may include graphing data.	Organize Students into Collaborative Groups where students collaborate, discuss, and brainstorm ideas. Group collaboration encourages them to combine their knowledge in different STEM areas, fostering interdisciplinary thinking. - Assign roles to students based on their strengths, such as data analysts, model designers, or research coordinators, to enhance collaboration. Encourage Model Construction Guide students to build a mathematical, conceptual, or physical model that addresses the problem. Encourage them to think critically about the factors involved, make assumptions, and create a systematic way to approach the problem. - Science Example: Students may use data analysis and environmental science principles to predict flood risks, incorporating variables like rainfall, soil absorption rates, and urban infrastructure. -Engineering Example: Students might design a physical prototype or use simulation software to test their flood prevention model. (AST, ACT, BST, BCT, CST, CCT,DCT,EST,ECT, GCT)

Engineering Design Process	*Model Eliciting Activity*
Present the Solution Finally, document the project and communicate the product and process to clients and others. This step may include a project portfolio or formal presentation.	Have students clearly document their problem-solving process, the development of their model, and how they applied their STEM knowledge. This documentation should include: - Assumptions made - Data used - Steps taken in model construction - Limitations of the model - Potential improvements Students then present their model to the class or a panel, explaining the rationale behind their approach, the results, and how their model can be applied to other similar problems. Guide Self-Assessment and Evaluation After constructing their model, students should evaluate it by testing different variables or conditions. Ask them to reflect on the accuracy, scalability, and real-world applicability of their model. (AST, ACT, BST, BCT, CST, CCT,DST,DCT,EST,ECT,GST, GCT) - Encourage students to test their model against known data or real-world situations, assessing its strengths and limitations. - Provide feedback to improve their models, helping them refine their assumptions and calculations (AST, ACT, BST, BCT, CST, CCT,DST,DCT,EST,ECT,GST, GCT)

4 CONCLUSIONS

The results of this research suggest that this collaborative effort can significantly enhance STEM integration, particularly within the unique natural resource context of Phuket. This approach not only fosters STEM instructional leadership but also promotes transdisciplinary integration, preparing students for STEM-related roles and careers. The study provides insights into what integrated STEM education can look like in practice within K-12 science classrooms, focusing on more than just the sequencing of engineering within a STEM unit (Crotty et al., 2017; Guzey et al., 2017). Our findings highlight varying degrees of integration and the ways in which the engineering design process can encourage students to create effective prototypes within an integrated STEM framework. Furthermore, the degree of integration seems related to teachers' awareness of how to make explicit and meaningful connections between disciplines, especially when implementing Model-Eliciting Activities (MEAs). If teachers see value in this integration, they may be more willing to invest time in helping students make these connections. While the teachers in this project received ongoing support throughout the implementation process, this level of assistance may not always be available when teachers are asked to engage in integrated STEM instruction in other contexts. Our findings suggest that teachers need time to reflect on student models during the engineering design process as they navigate the challenge of integrating multiple disciplines in their classrooms. Those who prioritize making explicit connections between subjects, such as the teachers in Cases AST, ACT, BST, BCT, CST, CCT, DST, DCT, EST, ECT, GST, and GCT, are likely to continue regularly interweaving multiple disciplines in their instruction. Creating real-world, meaningful contexts was emphasized in both the professional development and STEM integration framework (Moore et al., 2014), and was identified by teachers as a key factor in their success. However, maintaining a compelling and realistic storyline to keep students engaged proved challenging for these teachers, a difficulty unique to integrating engineering into K-12 instruction. This challenge forced teachers to think critically about how science is applied in real-world contexts. The introduction of a STEM-integrated unit represents a significant shift in the traditional physical science classroom, and even experienced teachers felt a degree of insecurity. They were compelled to reevaluate how they balance teaching science and math content, guiding students through engineering design challenges using MEAs, and integrating these subjects. Moving forward, we believe that future integrated STEM instruction with MEAs will require greater support for engineering integration. This can be achieved by explicitly following key steps to effectively use MEAs in educational settings: 1) Understand the Core Principles of MEAs**: MEAs are designed to reveal participants' thinking and encourage them to create models to solve real-world problems. These activities focus on model construction, emphasizing problem-solving and interdisciplinary connections. MEAs emphasize: Model Construction: Engaging students in creating a mathematical or conceptual model; 2) Reality Principle: Ensuring the problem is meaningful and applicable to students' lives; 3) Self-Assessment: Encouraging students to evaluate their own solutions; 4) Documentation: Making students articulate and document their thought process clearly; 5) Shareability and Reusability: The model should be usable by others in similar situations; 6) Effective Prototype: Creating a model that can serve as a prototype for future problem-solving scenarios. Guide Students to Construct the Model Allow students to develop their model without direct instruction, but provide support by asking guiding questions, such as:

- What factors do you think are most important in solving this problem?
- How will you represent these factors in a mathematical or conceptual way?
- Can your model be used in other situations?

7) Facilitate Self-Assessment and Peer Review. model hold up when we increase the budget or reduce the number of attendees? How would you adjust it?" Peer review can also be beneficial, where students present their models to other groups for feedback. 8) Document and Present the Model. Ask students to clearly document their process, including how they came up with their model, the assumptions they made, and how it can be applied to other situations. Have them present their model to the class, explaining its components and how it solves the problem. Encourage students to use visuals (graphs, charts) to illustrate their model. And 9) Reflection and Iteration. After presenting, encourage students to reflect on the strengths and weaknesses of their model. Discuss ways it could be improved or adapted for future problems. This step reinforces the idea that models evolve and improve over time. By following these steps, you can explicitly use Model-Eliciting Activities to promote critical thinking, collaboration, and real-world problem-solving in your classroom. disciplines by leveraging science content through an engineering design challenge.

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AVAILABILITY OF DATA AND MATERIALS

Due to the permissions granted by the Institutional Review Board (IRB), the data utilized in this study cannot be shared with individuals or entities outside of those directly involved in the project. All research participants' data are protected and handled with strict confidentiality.

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